

# NEW METHODS OF GENERATION OF ULTRASHORT LASER PULSES FOR RANGING

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## INTRODUCTION

To reach the millimeter satellite laser ranging accuracy, the goal for nineties, new laser ranging techniques have to be applied. To increase the laser ranging precision, the application of the ultrashort laser pulses in connection with the new signal detection and processing techniques, is inevitable. The two wavelength laser ranging is one of the ways to measure the atmospheric dispersion to improve the existing atmospheric correction models and hence to increase the overall system ranging accuracy to the desired value.

We are presenting a review of several nonstandard techniques of ultrashort laser pulses generation, which may be utilized for laser ranging:

- \* Compression of the nanosecond pulses using stimulated Brillouin and Raman backscattering
- \* Compression of the mode-locked pulses using Raman backscattering
- \* Passive mode-locking technique with nonlinear mirror
- \* Passive mode-locking technique with the negative feedback

## BRILLOUIN AND RAMAN BACKWARD SCATTERING

The idea of obtaining a single subnanosecond light pulse by temporal compression of a nanosecond laser pulse was suggested in [1] and the compression cascade by backward stimulated scattering of passively Q-switched Nd:YAG laser pulses was experimentally demonstrated in [2]. We had been investigated the generation of monopulse from Q-switched Nd:YAP oscillator [3]. The experimental setup is in Fig.1. The resonator was formed by the concave mirror M1 and the plane output mirror M2 deposited on the front surface of the Nd:YAP laser rod (Nd:YAP1). The b-axis of the crystal Nd:YAP yields linearly polarized light

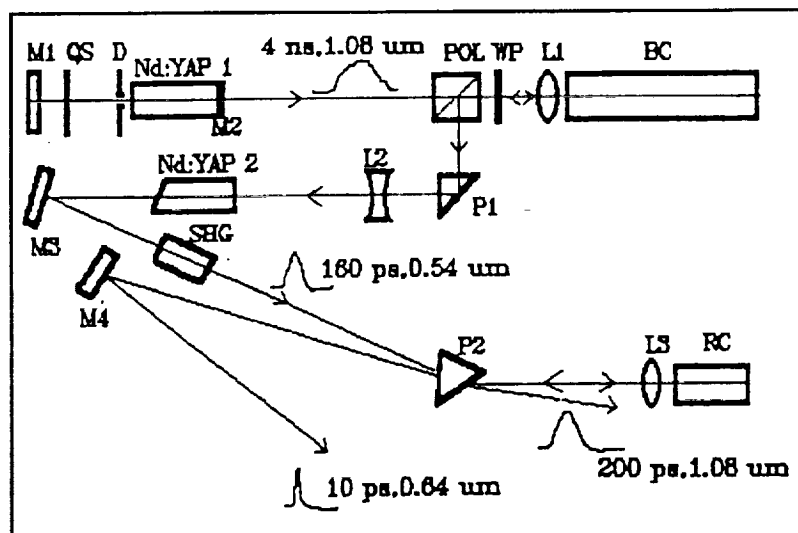


Figure 1 Experimental setup for two-stage pulse compression via stimulated backward scattering

mirror M1 and the plane output mirror M2 deposited on the front surface of the Nd:YAP laser rod (Nd:YAP1). The b-axis of the crystal Nd:YAP yields linearly polarized light output at  $\lambda_1 = 1.0795 \mu\text{m}$ . Q-switching was performed by the plastic BDN foil QS. The length of the resonator was 20 cm and together with low initial transmission of the Q-switch enable generation of pulses with duration  $\tau_1 = 4 \text{ ns}$  (Fig.2a). The pulse energy in TEM<sub>00</sub> mode was 7.5 mJ. This setup of short resonator gives most stable output pulses [4]. The oscillator radiation passing a cube dielectric polarizer POL and a quarter wave plate WP, was focused by lens L1 into SBS compressor - a 70 cm long cell BC filled with CCl<sub>4</sub>. When the necessary condition for SBS was fulfilled, the backward Stokes pulse was generated. The compressed Stokes pulse passing prism P1 and a negative lens L2 is amplified by the single pass Nd:YAP amplifier (Nd:YAP2) to the energy 30 mJ. The diverging beam is recollimated by the concave mirror M3. After frequency doubling in a SHG crystal, the pulse ( $\lambda_2 = 0.54 \mu\text{m}$ ) has an energy of 10 mJ. The radiation at different wavelengths is spatially separated by the dispersion prism P2. The  $0.54 \mu\text{m}$  pulse is then focussed with lens L3 into the second compressor consisting of the Raman cell RC filled with methane at 18 bars.

Temporal characteristics of the pulses in subnanosecond range were measured by the streak camera Imacon 500 with readout system consisting of SIT television camera, single frame memory and computer. The temporal resolution of the whole system was better than 2 ps [5]. Fig.2b shows the pulse after the first stage compression and the frequency doubling ( $\lambda_2 = 0.54 \mu\text{m}$ ). The mean pulse duration was  $\tau_2 = 160 \text{ ps}$ . Streak camera record of the backward Stokes pulse ( $\lambda_3 = 0.64 \mu\text{m}$ ) from the Raman cell is on Fig.2c. The mean value of the pulse duration  $\tau_3$  for given focussing optics depends on pump energy. The minimum length of pulse  $\tau_3 = 9 \text{ ps}$  was obtained for pump pulse energy 3-5 mJ.

The advantage of this compression technique in comparison to the used mode-locked picosecond lasers, are the absence of the active and/or passive mode lockers used to generate a train of picosecond pulses, and the absence of a fast electrooptical shutter used to select a single pulse from a train of pulses.

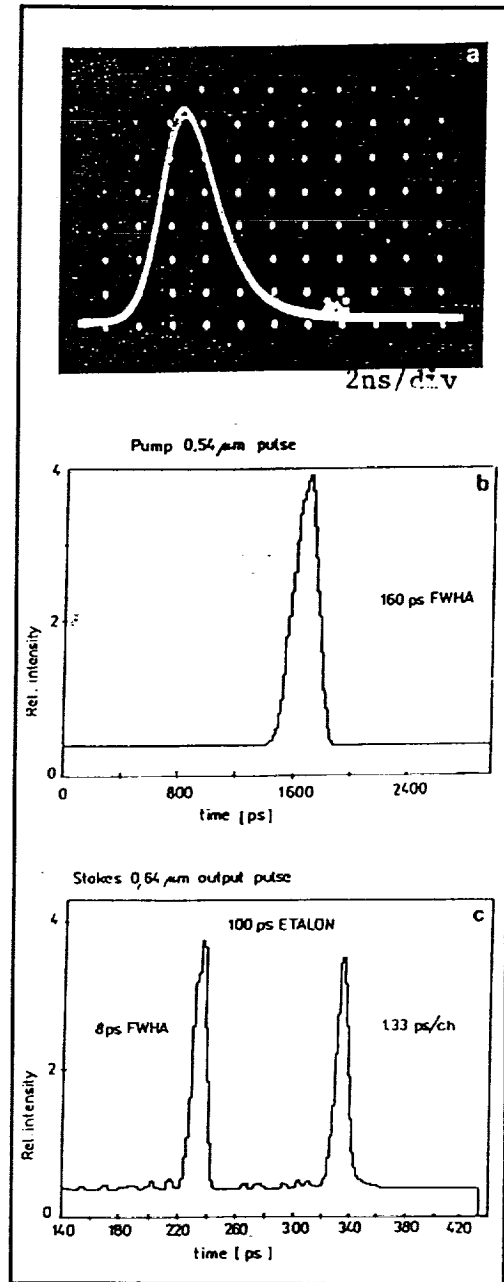


Figure 2 A records of compressed pulses

## RAMAN BACKSCATTERING PULSE COMPRESSION

The generation of single picosecond pulses through backward Raman scattering can start directly from the pulse train generated from a mode-locked laser. The experimental setup composes a passively mode-locked modified SFUR [6] loaded with 1/4"x4" Nd:YAG rod, delivering 30 mJ in a train of 4-5 pulses (FWHM) at  $\lambda_1 = 1.064 \mu\text{m}$  and with  $\tau_1 = 24$  ps timewidth and an amplitude fluctuation of the highest pulse in the train of 13%. The radiation is then converted to the second harmonic in a KDP crystal using type II configuration, giving 10 mJ and  $\tau_2 = 17$  ps timewidth, with a 20% amplitude fluctuation. The output train is then fed into the Raman cell, focussing it with a 160 mm focal length lens. The Raman cell was filled with 20 bars methane gas. On each shot, signals from fundamental, second harmonic  $\lambda_2 = 0.532 \mu\text{m}$  and Raman Stokes Backscattering at  $\lambda_3 = 0.68 \mu\text{m}$  were detected and stored for later processing. The Raman signal was checked to be the phase conjugated of the input second harmonic signal. Its energy was measured to be 3 mJ, giving an average green-to-red conversion efficiency of 30%. Time duration of the Raman pulses was  $\tau_3 = 7.4$  ps with a 2.3 compression factor with respect to second harmonic pulses. On Fig.4a is oscilloscope record of the rest of mode-locked train pulses (positive trace) and a single generated Raman pulse (negative trace). Fig.4b shows streak camera records of the overlap of 100 second harmonic pulses (positive trace) and Raman Stokes pulses (negative trace). The second harmonic radiation and Raman output pulses were detected by the independent photodiodes, one of the photodiode output was inverted and both signals have been added on the oscilloscope input.

This technique gives possibility to generate one ultrashort pulse without expensive optical and electronic part as they are Pockels cell, polarizers, high voltage pulse forming circuitry, optostart, high voltage power supply, etc. which are obviously needed to select single picosecond pulse from mode-locked train.

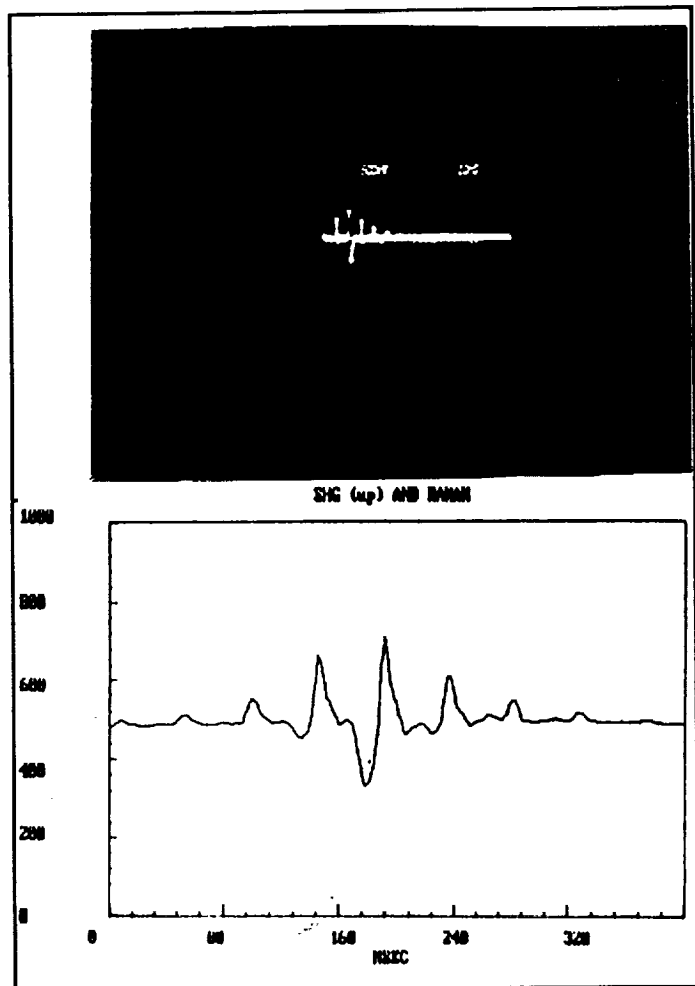
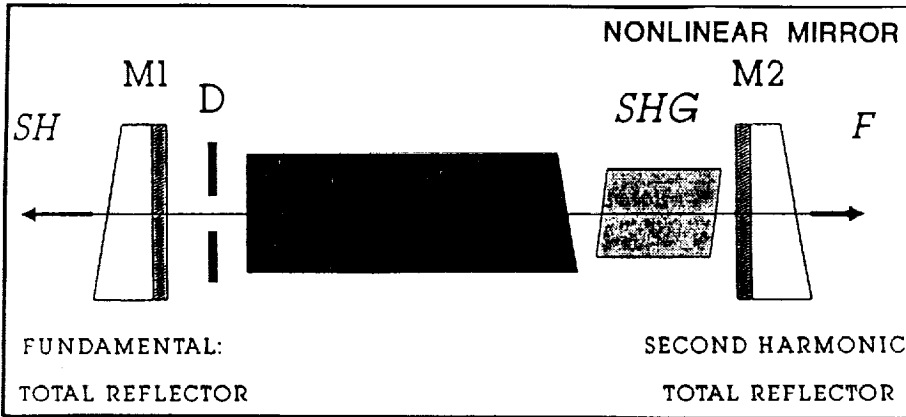


Figure 3 A records of the generated pulses

## GENERATION OF MODE-LOCKING PULSES USING A FREQUENCY-DOUBLING NONLINEAR MIRROR

The mode-locking technique based on intracavity frequency doubling offers new capabilities for generation of ultrashort laser pulses. A frequency doubler inside the cavity,

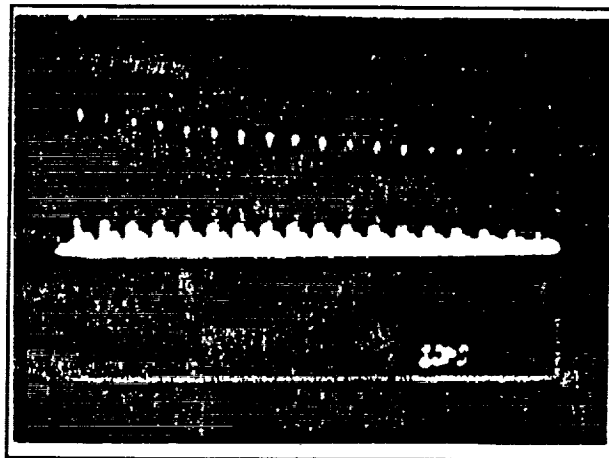


**Figure 4** Experimental scheme

together with an output mirror with high reflectivity at the second harmonic forms a nonlinear mirror, whose reflectivity at the fundamental wavelength can either increase or decrease when the input light intensity increases. When the phase condition facilitate increasing

reflectivity, the device can be used as a passive mode-locker. First experiment with the nonlinear mirror was performed by K. Stankov [8]. With the Nd:YAG laser active medium he got 20 ps length of pulses. We investigated the attractive potential of the second harmonic nonlinear mirror to mode-lock lasers at quite different wavelengths. The laser cavity was formed by the dielectric mirrors. In all cases the rear mirror was a total reflector at the fundamental, the output mirror was dichroic and it was total reflector at the second harmonic and had 20-24% reflectivity at the fundamental wavelength (Fig.4). Using a single 30°-cut LiIO<sub>3</sub> frequency doubler (20 mm long), mode locking at the 1.08  $\mu\text{m}$  and 1.34  $\mu\text{m}$  transitions of pulsed Nd:YAP laser was achieved [9]. Pulses as short as 40 ps and 15 ps at the corresponding wavelength were obtained. Mode-locking was achieved also in Er:YAP laser at 1.66  $\mu\text{m}$  wavelength with pulse duration of 450 ps [10] and in Ti:Sapphire laser at 0.7  $\mu\text{m}$  wavelength with pulse duration of 100-130 ps [11]. A comparative wavelength indicates that the minimum pulse duration is determined by the limited number of round trips only.

This experiment showed that nonlinear mirror technique allows to mode lock a number of solid state lasers ranging in wavelength 0.8  $\mu\text{m}$  (Ti:Sapphire laser) up to 1.66  $\mu\text{m}$  (Er:YAP laser). When the optimization will be done and shorter pulses will be generated, the advantages of short pulse immediately with the generation of first and second harmonic radiation will be evident.



**Figure 5** The mode locked Ti:Sapphire laser (10 ns/div)

## PASSIVE MODE-LOCKING TECHNIQUE WITH THE NEGATIVE FEEDBACK

The solid state lasers with negative feedback through an electro-optic loss that limits the maximum intensity inside the cavity and prevents the rapid growth of the laser pulse, were successfully used for the generation of shorter reproducible pulses [12,13]. The possibility of using a passive two-photon absorption element instead of the active loss control, was also suggested and demonstrated [14,15,16]. Two-photon absorber (GaAs or CdSe) acts

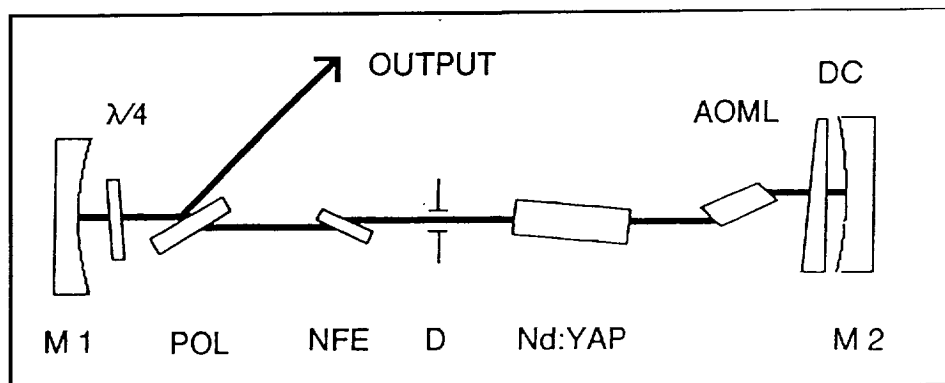


Figure 6 The experimental setup

inside the resonator as a passive negative feedback element (NFE). The scheme of experiment with Nd:YAG or Nd:YAP laser is similar and it is schematically shown in Fig.6.

The Fabry-Perot cavity is formed by concave mirrors M1 and M2 ( $R=10\text{m}$ ) having a reflectivity of 99.8%. The mirror M2 is in contact with a 0.5 mm thick dye cell (DC) containing flowing Eastman Kodak 9860 dye in 1,2-dichloroethane ( $T_0=30\%$  at  $1.08\text{ }\mu\text{m}$ ). The output coupling of the resonator is achieved by means of a dielectric polarizer (POL), which, in combination with the quarter-wave plate keeps the output coupling at 50%. The active medium was Nd:YAG or Nd:YAP. The cavity round trip time was synchronized to the modulation period of the acoustooptic mode locker. With the Nd:YAG laser long trains of steady-state pulses was generated, with a single pulse time duration of 10 ns and an energy of  $10\text{ }\mu\text{J}$ , with cw comparable stability. The minimum of pulse duration was obtained for Nd:YAP laser with CdSe working as a negative feedback element. In this case, the pulses with 5 ps length was generated with an energy of 1 mJ. The example of the generated pulse trains for different negative feedback elements are in Fig.7.

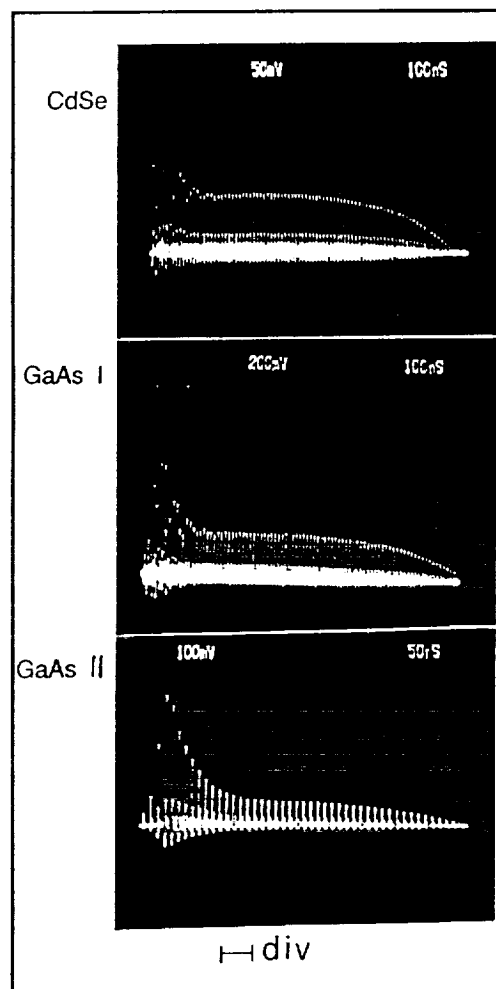


Figure 7 The records of the generated pulses

## CONCLUSION

This review article shows some possibilities for generation of short and ultrashort laser applicable in laser ranging.

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